Nearshore Bedload Sediment Transport

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LONG-TERM GOALS

To understand the physics of sediment transport by waves and currents and to use that understanding to predict the evolution of nearshore bathymetry given the nearshore fluid velocity and acceleration fields. A secondary goal is to interpret the environment of deposition and the offshore wave climate from the sedimentary record.

OBJECTIVES

Objectives are to theoretically describe and numerically model the substantial effects of fluid acceleration on sheet flow bedload transport in the surf zone, to determine the dominant processes governing grain segregation by size and density during transport, to generate computer simulation models for evolution of nearshore morphology and other grain-scale sedimentary processes, and to suggest field and laboratory experiments needed to advance understanding of sediment transport processes.

APPROACH

Discrete particle models for bedload transport processes describe the motion of individual sediment grains subjected to fluid and body forces by integrating F=ma at small time steps. Our models predict transport rates, dispersion and sorting of grains having a distribution of sizes and densities. They are well-suited for describing transport processes as a function of grain size in the swash and surf zones, where variations in particle size (as well as other properties) may be large. Description of such variations does not merely refine existing models; for instance, large and small grains in the nearshore have been observed to move in opposite directions. The model is also well-suited for studies of other sea-bed phenomena, for instance, the penetration of impactors into the sea floor as described below. We continue to address fundamental problems concerning fluid-particle interactions within the discrete-particle modeling framework.

Cellular automata models use sediment transport relationships codified from discrete-particle models to extend those calculations to longer length and time scales, in effect coarser-graining the particle-by-particle models. Our work using cellular automata models is still in its exploratory stages and shows considerable promise.

WORK COMPLETED

AASERT-supported graduate student Joe Calantoni used a discrete-particle simulation model for bedload transport to study sheet flow transport of coarse sand having a distribution of particle sizes under a variety of typical nearshore conditions, including broken and unbroken waves and varying local bed slopes (Calantoni and Drake, 1998a,b; 1999a,b). Calantoni developed a model that describes the effects of fluid acceleration on bedload transport under sheet flow conditions in terms of the fluid impulse, which can be calculated from commonly available near-bed velocity measurements (Drake and Calantoni, in press). Generality of the discrete-particle model allows application to such problems as simulation of sea-bed penetration studies (described in FY00 report).

Calantoni's work in FY01 focused on discrete-particle modeling of 1) the effects of local bed slope on bedload transport rates under various waveforms typical of the surf zone (Figure 1) and 2) processes that segregate particles by size and density. Segregation by size is particularly important in the swash zone at Duck NC, where gravel particles having diameters up to several mm are commonly interspersed with finer sands having typical diameters from 0.1 mm to 0.2 mm.

Graduate student Chris Thaxton modified the surf-zone wave model RBREAK (e.g., Kobayashi and Wurjanto, 1992; Raubenheimer *et al.*, 1995) to incorporate several different sediment-tranport relationships as a first step in a longer-term effort to model nearshore evolution with NOPP collaborators. Bedload transport rates are typically calculated in the model as a function of grain size (based on Calantoni's results), and evolution of the bottom roughness and grain size distribution are calculated as a function of cross-shore location.

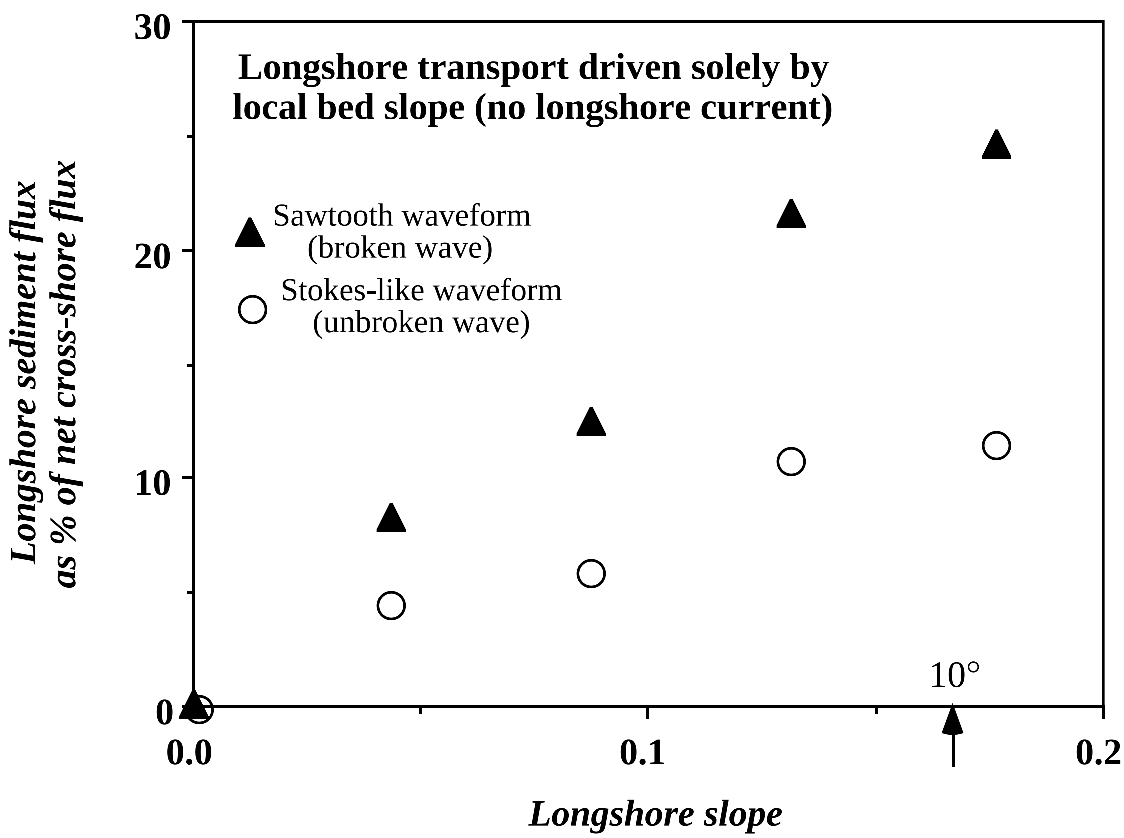

Figure 1. Longshore transport is generated during cross-shore bedload transport when the longshore slope is non-zero -- the grains simply move in the direction of the local bed slope, even when there is no component of fluid motion in the direction of grain motion. Here the longshore sediment flux is shown for two simulated waveforms characteristic of the surf zone; the cross-shore slope is zero and all fluid motion is restricted to the cross-shore direction. Solid triangles indicate the longshore transport as a percentage of the net cross-shore transport rate under a sawtooth-shaped waveform characteristic of broken waves or bores. Open circles indicate longshore transport under unbroken Stokes-like waves. Longshore transport under both waveforms varies linearly with slope, increasing from zero for no longshore slope to roughly 25% for longshore slopes of about 10 degrees for the sawtooth waveform, and about 10% for the Stokes-like waveform.

RESULTS

Effects of local slope on bedload transport: Local bed slope in the surf zone often has components in both cross-shore and alongshore directions. At scales on the order of a meter, Local slopes can be much greater than a few degrees, for which small-angle approximations are appropriate, and at small length scales, may reach the angle of repose (around 30 degrees) on megaripple slipfaces. Surprisingly, energetics formulae for bedload transport in the surf zone address only the cross-shore component of bed slope, and thus predict zero sediment flux due to gravity except in the cross-shore direction, although significant net alongshore transport can occur for an alongshore sloping bed even when net cross-shore transport is zero. Over small length scales these neglected contributions to transport are clearly important in the morphodynamic evolution of ripples, megaripples and perhaps larger bed undulations of unknown origin. Specifically, the diffusion-like motion of sediment along the crests of bed forms are one of the major mechanisms responsible for the creation, migration and annihilation of bedform defects, which in turn govern the time scales over which bedforms are created and respond to changes in flow conditions (Werner and Kocurek, 1997; 1999).

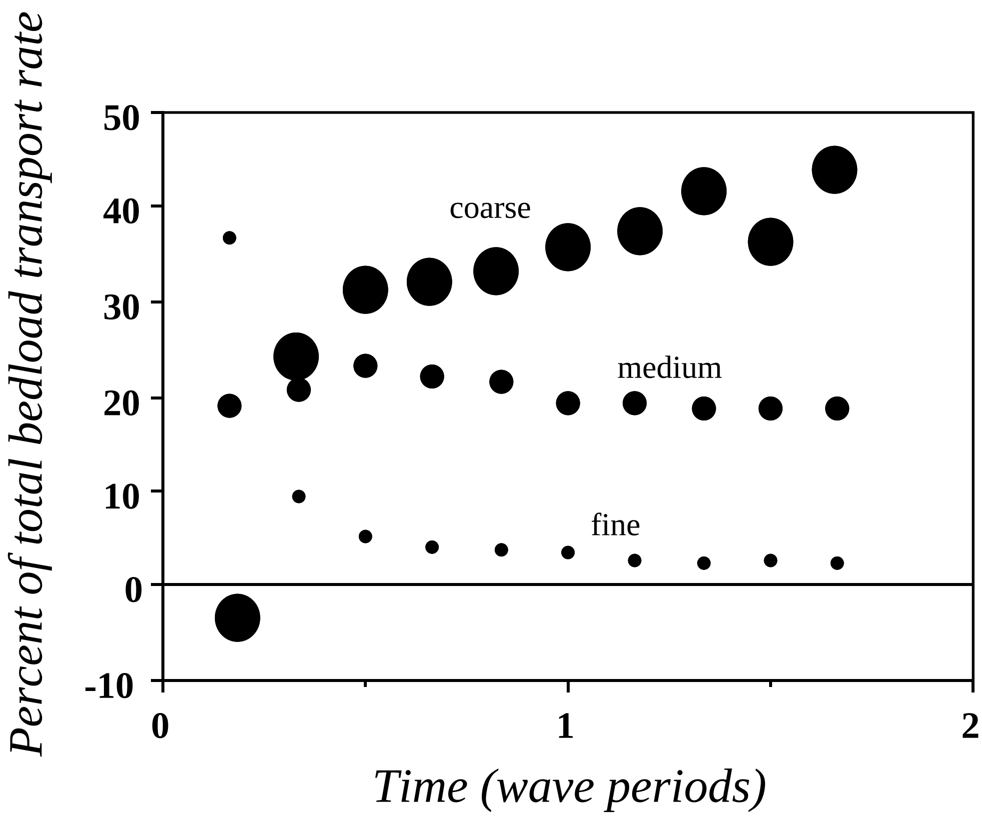

Figure 2. Bedload transport rapidly segregates grains by size. Simulation of grains having the density of quartz and a roughly gaussian distribution of sizes ranging from 0.5 mm diameter (fine) to 1.5 mm diameter (coarse). Mean grain diameter is 1.1 mm (medium), wave period is 6 s and maximum free-stream fluid velocity is 1 m s^{-1} for a sawtooth waveform characteristic of broken waves in the surf zone. During the first second of transport, the finer grains comprise nearly 40% of the total transport rate, but after 3 s the transport rate of the fine grains is less than 10% and the rate for coarse grains is about 30% of the total. Large grains rise to the top of the shearing bedload layer while finer ones fall toward the immobile bed. Total transport rates sum to less than 100% because intermediate size fractions were omitted for clarity.

Size segregation of bedload particles during transport: Bedload transport processes segregate grains by size and density when the distribution of grain sizes departs from uniform (Figure 2). While the size distribution of sand comprising most of the SandyDuck experimental beach is sharply peaked, in the swash zone the distribution and its width are variable in both space and time. The grain size distribution is commonly described by a single descriptor, often the mean grain diameter for calculations of nearshore bedload transport. Work to date using discrete particle simulations indicates that transport rates for different grain sizes can vary by factors of two to three or more for size distributions which include a wide range of sizes. In particular, distributions including sand and gravel show the largest disparities in transport rates. Visualization of simulation results clearly indicate the operative mechanism: as grains are sheared in the bedload layer under sheet flow conditions, larger grains rise to the top of the bedload layer while smaller grains fall into relatively more protected, slower moving regions of the layer. Such "inverse grading" (coarse grains lying above finer ones) is commonly observed in nearshore deposits and elsewhere in the geologic record. This sorting phenomenon has been extensively studied in the context of dry granular materials (e.g., Jaeger & Nagel, 1992).

IMPACT/APPLICATION

Effects of both local bed slope and grain size segregation during bedload transport in the nearshore must be included in models for bathymetric evolution. At small length scales, the generation and maintenance of angle-of-repose slipfaces on such bed forms as megaripples exert a strong influence on bed roughness, and in turn, surf zone currents. Transport of grains of differing sizes in the surf zone has important implications for understanding bathymetric evolution, particularly in the swash zone where large particles are common. Accumulation of gravel and shell fragments in the swash can greatly affect infiltration rates, which are thought to directly influence shoreline erosion and deposition processes (e.g., Turner & Masselink, 1998). Continued fundamental development of discrete-particle modeling capabilities will aid studies of sea-floor geophysical properties for a variety of applications.

RELATED PROJECTS

Discrete-particle and cellular-automata simulation studies are also supported by a National Ocean Partnership Program grant for "Development and Verification of a Comprehensive Community Model for Physical Processes in the Nearshore Ocean."

Results from bedload transport simulations are used to provide information to construct synthetic sedimentary environments for studies of acoustic propagation in nearshore sediments by graduate student David Pierson under ONR grant #N00014-00-1-0459 "Acoustic Time-Reversal Mirrors."

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